Meaningful questions: The acquisition of auxiliary inversion in a connectionist model of sentence production ☆

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ABSTRACT

Nativist theories have argued that language involves syntactic principles which are unlearnable from the input children receive. A paradigm case of these innate principles is the structure dependence of auxiliary inversion in complex polar questions (Chomsky, 1968, 1975, 1980). Computational approaches have focused on the properties of the input in explaining how children acquire these questions. In contrast, we argue that messages are structured in a way that supports structure dependence in syntax. We demonstrate this approach within a connectionist model of sentence production (Chang, 2009) which learned to generate a range of complex polar questions from a structured message without positive exemplars in the input. The model also generated different types of error in development that were similar in magnitude to those in children (e.g., auxiliary doubling, Ambridge, Rowland, & Pine, 2008; Crain & Nakayama, 1987). Through model comparisons we trace how meaning constraints and linguistic experience interact during the acquisition of auxiliary inversion. Our results suggest that auxiliary inversion rules in English can be acquired without innate syntactic principles, as long as it is assumed that speakers who ask complex questions express messages that are structured into multiple propositions.

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1. Introduction

A central debate in language acquisition concerns the question which aspects of our knowledge of language are learned from experience and which are part of our biological endowment for language. Nativist theories have argued that there are syntactic principles that are impossible to learn given the input that children receive (Chomsky, 1968, 1980). A prominent example of such an unlearnable principle is the structure dependence of linguistic operations which seems ubiquitous in language. It is most commonly illustrated in terms of auxiliary inversion in English yes-no questions (also called *polar* questions). In transformational grammars (Chomsky, 1981), polar questions are derived from declarative sentences by auxiliary movement. For instance, declaratives with progressive verbs place the auxiliary *is* before the verb *jumping* as in (1) and this auxiliary is moved to sentence initial position in polar questions (2).

(1) The boy is jumping.
(2) Is the boy _ jumping?

Put this way, the auxiliary inversion rule is simple and should be learnable but it becomes more challenging when there are multiple auxiliaries in complex declaratives like (3) with two clauses.

(3) The boy that is jumping is happy.

When the polar question version of (3) is created as in (4), the main clause auxiliary is moved to sentence initial position, rather than the embedded clause auxiliary as in (5).

(4) Is the boy that is jumping _ happy?
(5) *Is the boy that _ jumping is happy?

Chomsky (1980) argued that the syntactic knowledge that supports the correct structure (4) is not obviously explained by the input to children. If children only hear single-clause questions with

one auxiliary (2) or right-branching questions with two auxiliaries (6),

(6) Is the boy _ chasing the cat that was lazy?

then the input would be consistent with an incorrect rule that creates ungrammatical questions like (5) where the linearly first auxiliary is placed in sentence initial position.

In order to learn the correct rule, children would need to hear center-embedded polar questions with two auxiliaries (4), but these questions appear to be rare in child-directed speech. MacWhinney (2004) found only one occurrence in approximately 3 million utterances (up to age 5;0) in the CHILDES database (MacWhinney, 2000; see also Legate & Yang, 2002). The absence of positive exemplars has been argued to demonstrate the *poverty of the stimulus* with respect to auxiliary inversion in complex questions. On this view, the input to children does not contain enough information to acquire the linguistic rules that adult speakers appear to use (Berwick, Pietroski, Yankama, & Chomsky, 2011; Chomsky, 1980; Crain, 1991; Laurence & Margolis, 2001). The *poverty of the stimulus* and the compatibility of the input with an incorrect linear order rule have been taken as evidence in support of innate syntactic knowledge. This argument has made auxiliary inversion in complex questions the prototypical defense of linguistic nativism and it is presented in virtually all introductions to syntactic theory (e.g., Carnie, 2012; Radford, 2004) and first language acquisition (e.g., Ambridge & Lieven, 2011; Clark, 2002; Karmiloff & Karmiloff-Smith, 2002).

An alternative to nativist accounts of auxiliary inversion are constructivist, or usage-based, theories of language (Bybee, 2010; Goldberg, 2006; Tomasello, 2003). These theories argue that the input from which children learn is richer than has been assumed by nativists, and that children use powerful statistical learning mechanisms to gather information from this data (Gómez, 2007; Saffran, Aslin, & Newport, 1996). For example, Reali and Christiansen (2005) have suggested that word co-occurrence statistics suffice to render grammatical questions (4) more probable than their ungrammatical counterparts (5) and Pullum and Scholz (2002) have argued that complex questions other than (4) can provide evidence for the correct auxiliary inversion rule (see also Sampson, 1989). Thus, usage-based theories have shifted the explanatory burden away from innate syntactic knowledge and onto the learning mechanism and its input.

Although these approaches differ in where they seek relevant constraints on complex question formation, they both locate these constraints within the domain of language. English auxiliary inversion rules are either learned from linguistic input or preset by innate syntactic constraints. In the present work, we propose an alternative account where auxiliary inversion arises from constraints that are outside of language. In particular, we focus on the role of the message that is conveyed when complex questions are being produced. Our claim is that the message is structured into nonlinguistic propositions and this structure constrains the way grammars can develop in the language system. Critically, we argue that the message structure is available before children acquire the ability to produce complex questions. We provide a computational model that is able to use the structure of meaning when learning to produce grammatical complex polar questions from impoverished input.

1.1. Framing the learning problem

Nativist and constructivist theories generally agree that some aspects of question formation are learned from the input. This is because auxiliary inversion in interrogatives is typologically rare and limited to a handful of predominantly West-Germanic lan-

guages (Siemund, 2001). Most languages mark polar questions in other ways and therefore different realizations of interrogative form must be acquired through experience. Speakers of English learn to front auxiliaries in interrogatives and in nativist theories, learning is modulated by a constraint on the grammar space that blocks the incorrect rule from being adopted (Crain & Pietroski, 2001; Crain & Thornton, 2012). This constraint has been called *structure dependence* because transformations are sensitive to the hierarchical phrase structure of sentences. For example, sentence (3) would have a syntactic structure where each clause is dominated by its own $\mathcal{S}$ node (matrix $\mathcal{S}1$, embedded $\mathcal{S}2$) as in (7).

(7) [The boy [that is jumping]$_{\mathcal{S}2}$ is happy.]$_{\mathcal{S}1}$

Structure dependence constrains the language system to consider only rules where auxiliaries do not move out of their $\mathcal{S}$ domain, and this would guarantee the acquisition of the correct rule where only the matrix auxiliary can be displaced. The constraint is domain-specific because it is formulated in terms of linguistic categories.

Constructivist theories, on the other hand, have questioned whether an innate syntactic constraint is required to learn auxiliary inversion (Ambridge, Pine, & Lieven, 2014; Clark & Lappin, 2011; Pullum & Scholz, 2002) and the nature of errors that children make throughout development has been an important source of evidence in this debate. In an elicited production study, children between 3;2 and 4;7 never omitted the embedded clause auxiliary as in (5), and this seemed to support the innateness of a structure-dependent constraint (Crain & Nakayama, 1987). Using the same paradigm, however, Ambridge, Rowland, and Pine (2008) found that such errors could be elicited when target items contained modal auxiliaries or plural copulas, undermining the nativist line of reasoning. Moreover, 62% of the responses in Crain & Nakayama's study contained other kinds of errors and older children [6;3–7;9] tested in Ambridge et al. still produced 52.6% incorrect questions. This suggests that the acquisition of complex questions is a slow, gradual process that requires accumulation of relevant evidence over an extended period of time. A frequent error type in both studies was *auxiliary doubling* where the main clause auxiliary was repeated after the relative clause (e.g., *Is the boy who is jumping <u>is</u> happy?*) which is difficult to reconcile with the idea that question formation involves auxiliary movement as a displaced constituent should not persist in its canonical location. If questions are not derived from declaratives by movement (Ambridge, Rowland, Theakston, & Tomasello, 2006; Bouchard, 2012; Dąbrowska & Lieven, 2005; Rowland & Pine, 2000), there would be no need for a structure-dependent constraint restricting auxiliary inversion. Others have argued that these errors are due to performance limitations (Crain & Nakayama, 1987), but then a theory is needed which explains why these limitations change over development.

Nativist and constructivist approaches are often treated as polar opposites and it is helpful to delineate their assumptions from a more abstract perspective. Language is a neurobiological system whose configuration is determined by the values of its internal parameters (e.g., the strength of $\sim 10^{14}$ synaptic connections). The set of realizable values is the language network's model space. Each point in the space implicitly represents the grammar currently adopted by the learning child (Fig. 1). During acquisition, input interacts with learning biases and maturational constraints to force the system into a region of model space which represents adult knowledge of language. Linguistic nativism assumes that the learner never entertains grammars where structure dependence is violated because an innate syntactic constraint removes such grammars from the model space (shaded region in left panel of